157-nm Lithography for 100-nm Node Challenges and Progress

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Acknowledgment

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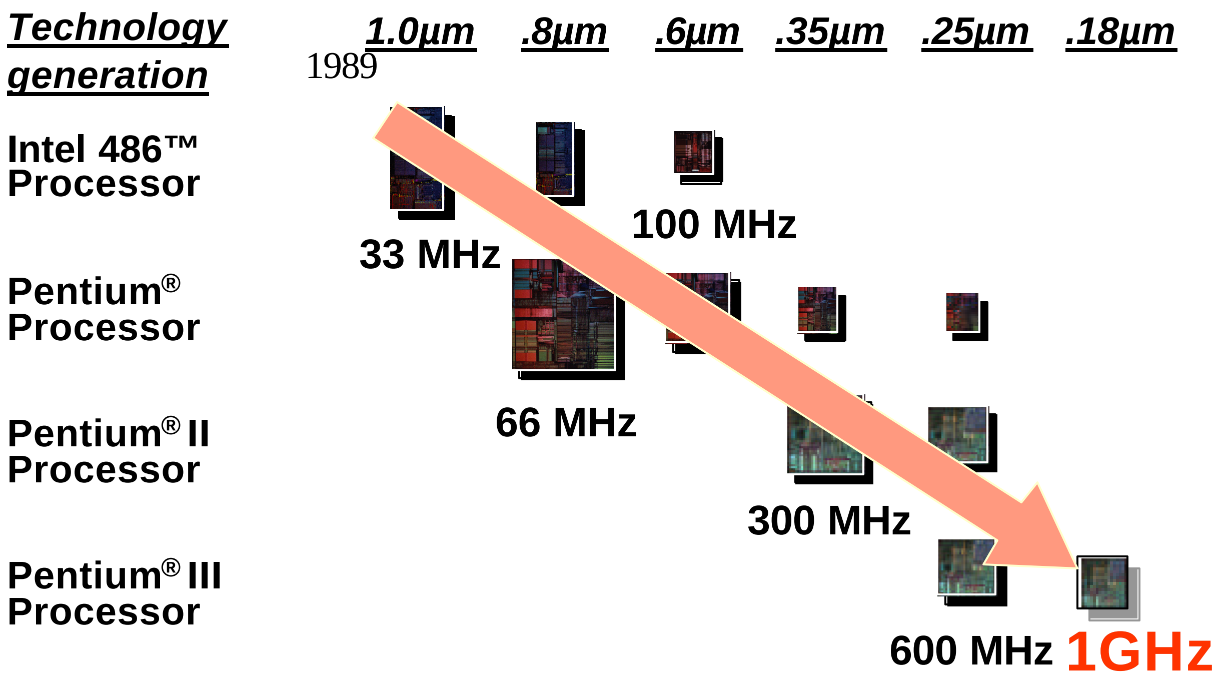
Outline

- Intel's Microprocessor Technology Cycle
- Technology Treadmill and Roadmap Requirements
- Roadmap Technical Strategies
- 157-nm Lithography Challenges and Status
    - Schedule: 2X Schedule Compression
    - Optical Design: Materials and Lasers
    - System Purging: Most Recent Accomplishments
    - Resist:Issue/Strategy/Most Recent Results
    - Mask: Materials and Handling
- Summary

Intel uP Technology over 10 years

Technology scaling drives higher performance and density



Technology Treadmill and Roadmap Requirements

HVM Year	Generation	Gate Length	SRAM Cell	K1
1989	1	1	220	1
1991	0.8	0.8	111	
1993	0.5	0.5	44	
1995	0.35	0.35	21	
1997	0.25	0.2	10.6	0.65
1999	0.18	<0.13	5.6	0.55
2001	0.13	<0.10	<2.5	0.45

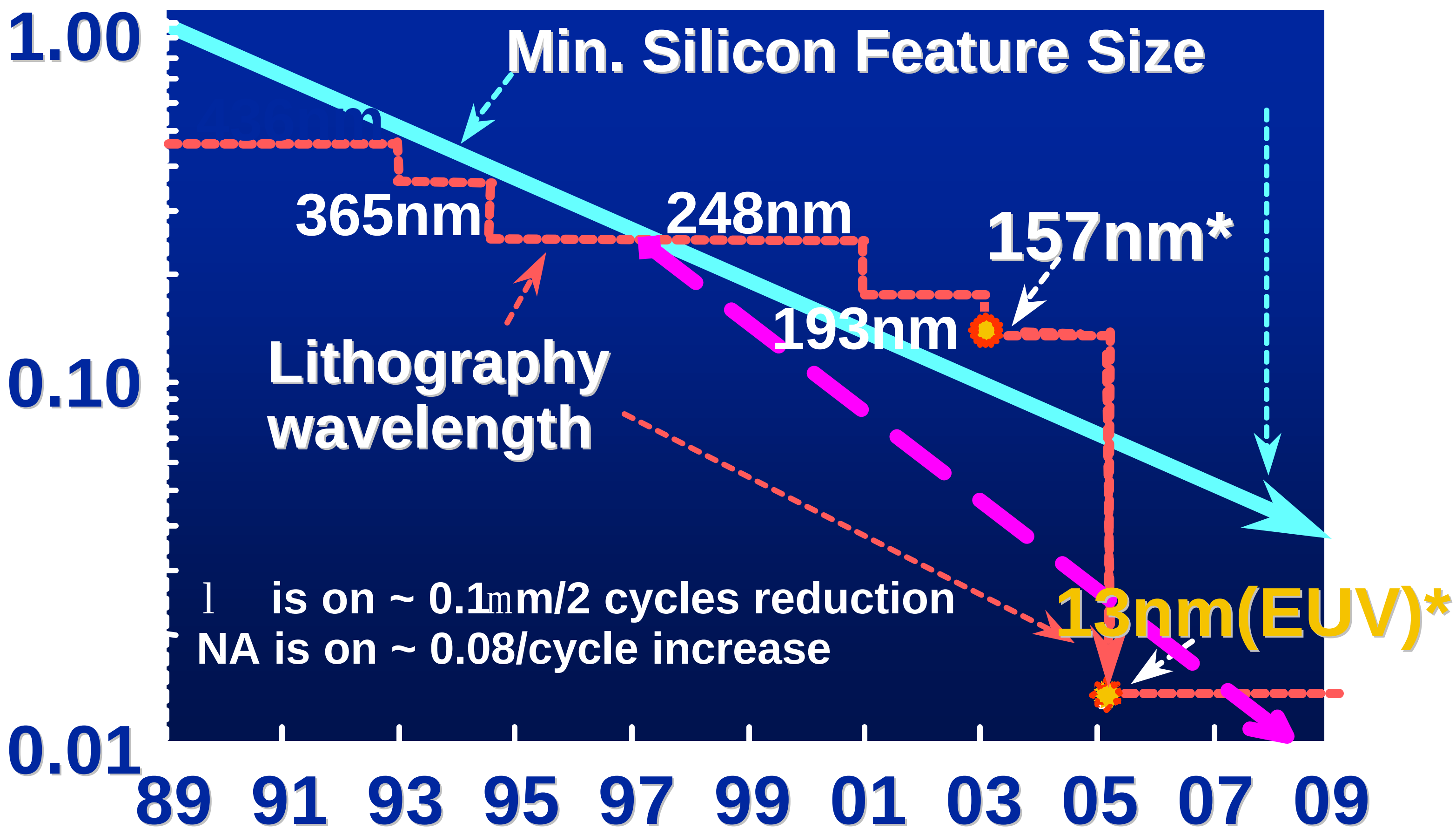
- **Intel is on 2 year/Technology cycle treadmill for 10 years**
- **k_1 is on ~ 0.1/cycle reduction over that time**

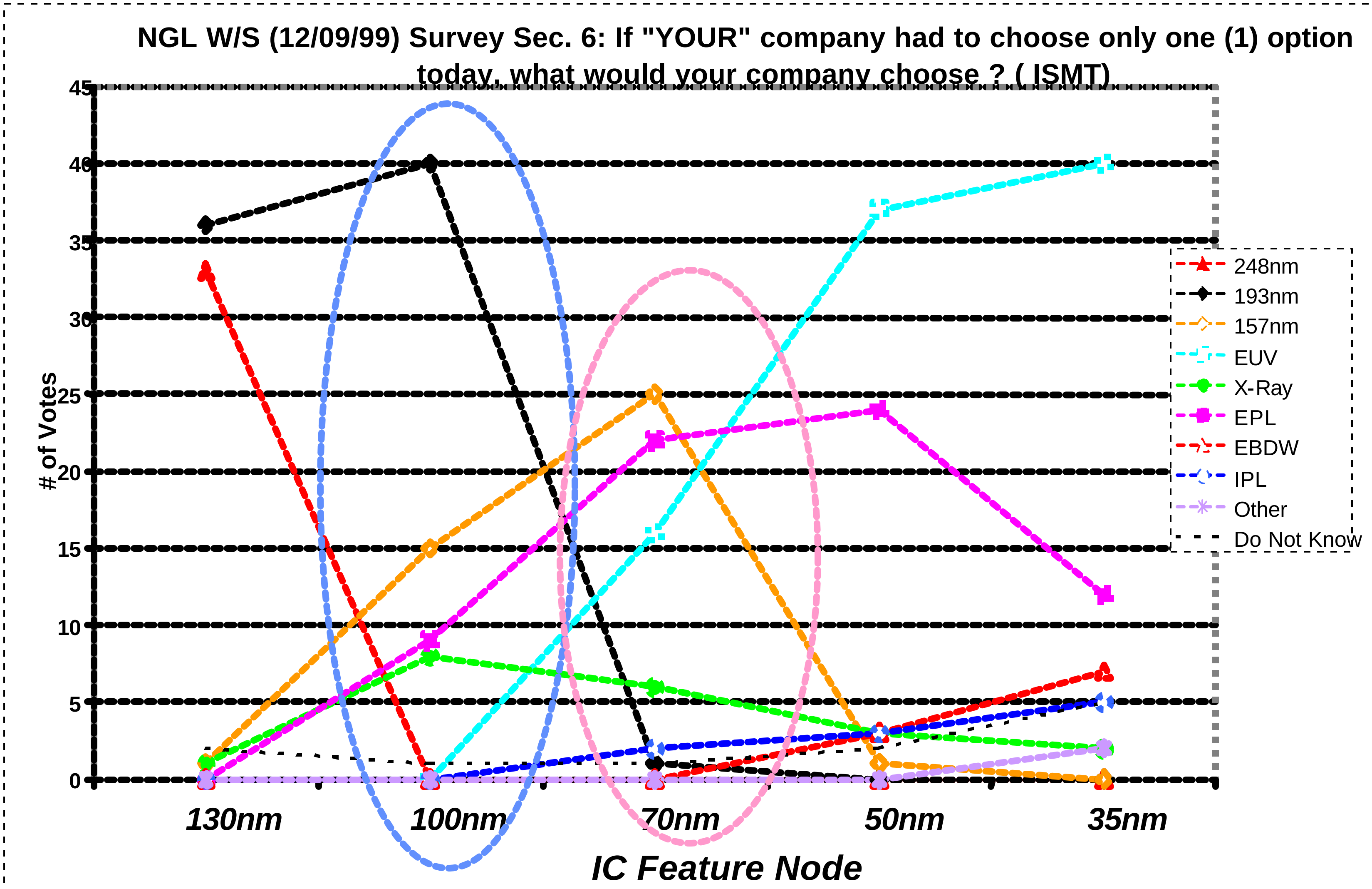
Roadmap Requirements: (1) Maintain 2 year-cycle, (2) Scale pitch (density) at 0.7X per generation, and scale gates at faster than 0.7X per generation

Roadmap Technical Strategy

* Use wavelength reduction to drive the pitch roadmap
  - ⇨ Keep the basic technology roadmap simple: Topic of Today's Talk
* Use wavelength reduction + resolution enhancement to drive the gate roadmap
  - ⇨ Gates are now "two generations ahead"

Wavelength Reduction To Drive The Pitch Roadmap: 157-nm for 100-nm Node





NGL W/S (12/09/99) Survey Sec. 6: If "YOUR" company had to choose only one (1) option today, what would your company choose ? (ISMT)
45
40
35
30
25
20
15
10
5
0
# of Votes
130nm
100nm
70nm
50nm
35nm
IC Feature Node
248nm
193nm
157nm
EUV
X-Ray
EPL
EBDW
IPL
Other
Do Not Know

157-nm Lithography Challenge: Schedule

157nm - Got to be “D faster!

'88 '89 '90 '91 '92 '93 '94 '95 '96 '97 '98 '99 '00 '01 '02 '03

Start LL Program

Proof of Concept

Industry Consensus

Mini stepper

Beta scanner

HVM scanner

Development Schedule Is 2X Compression

Start LL Program

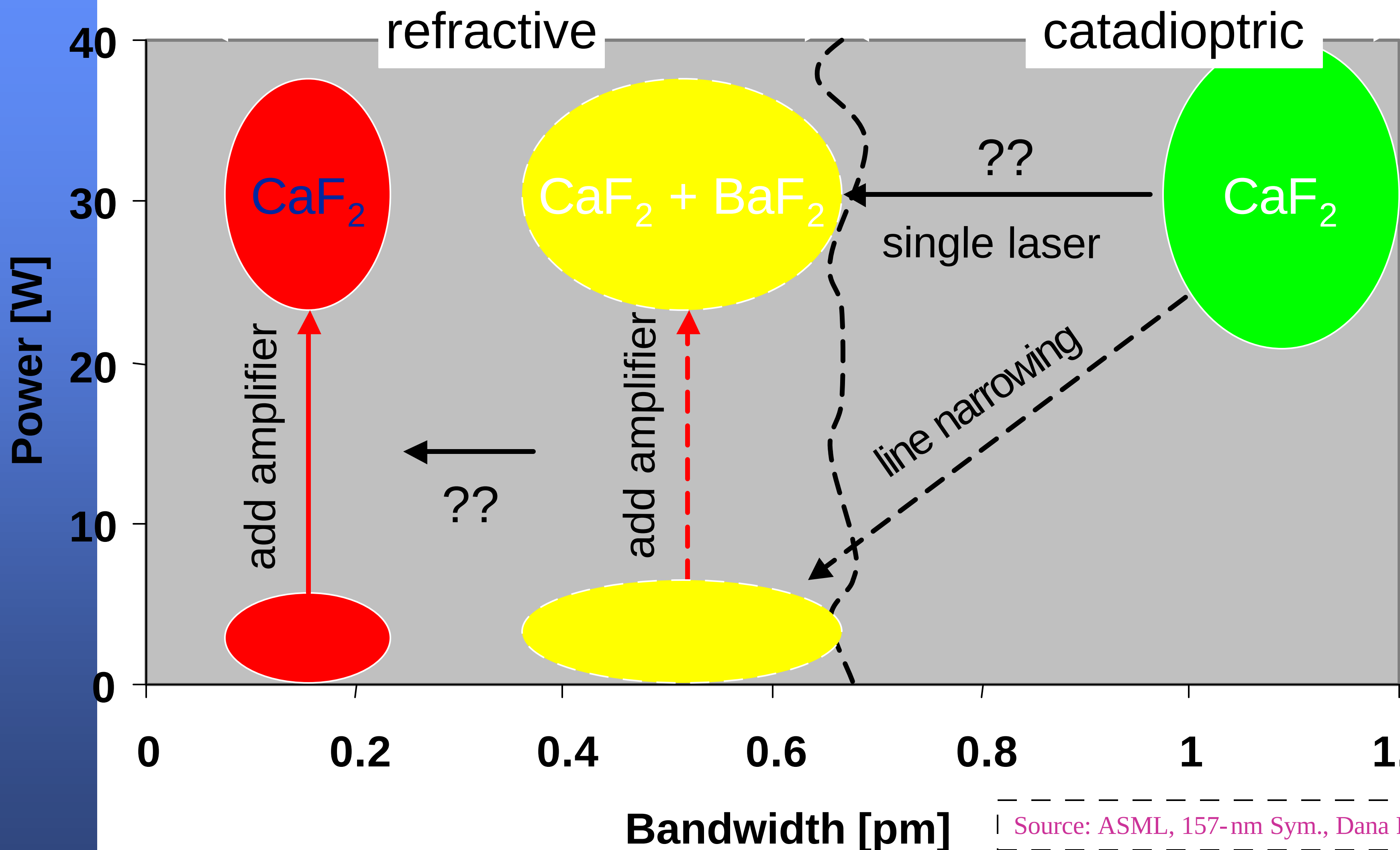
Industry Consensus

Mini scanner

Beta scanner

HVM scanner

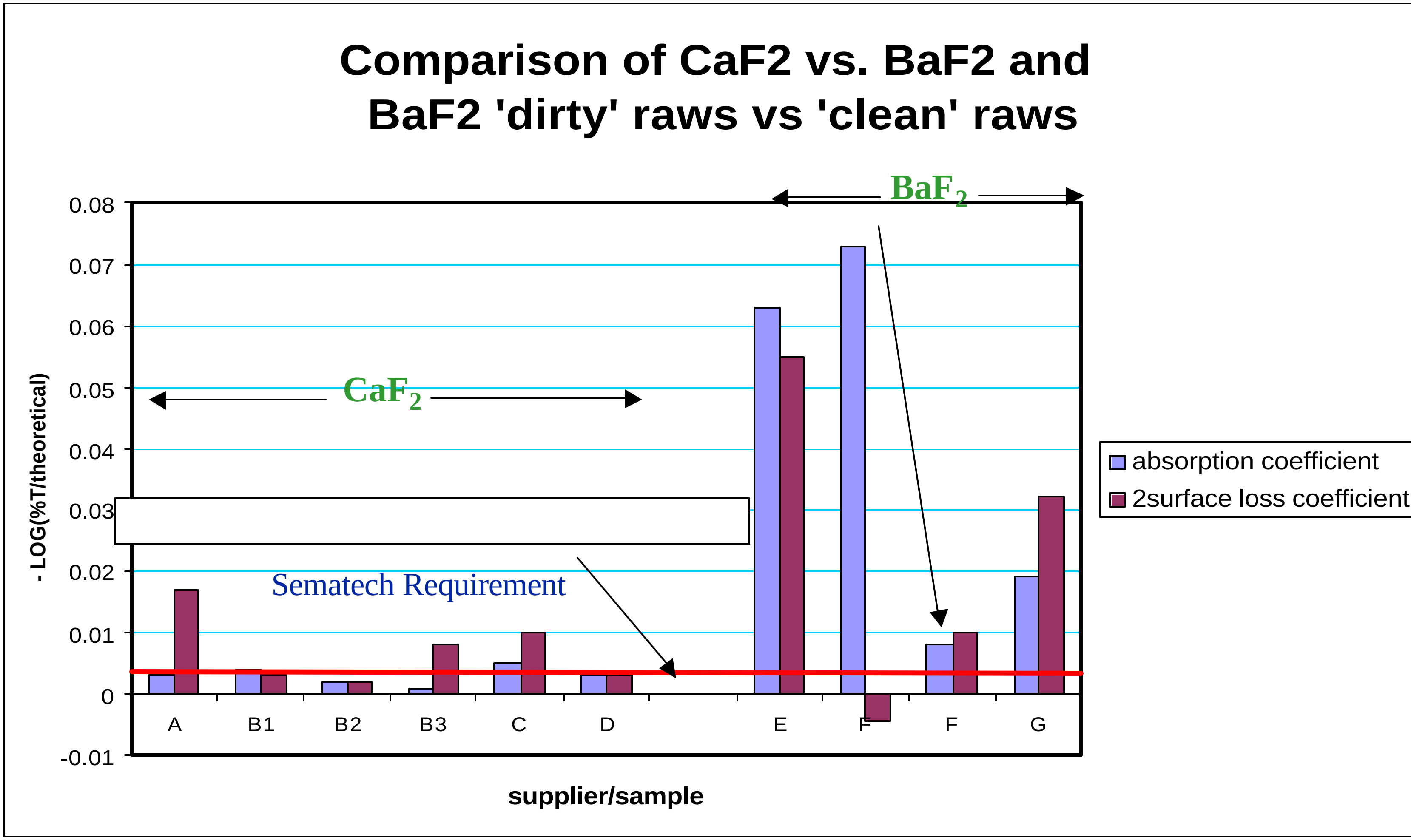
Laser power and lens concept



Source: ASML, 157-nm Sym., Dana Point

Laser and Lens Material Availability Limits Optical Design

Lens materials



Good progress made in BaF_2 as second lens material

Laser Status

- Recent measurement of natural bandwidth to be 0.6-pm should improve catadioptric lens performance and gets closer to laser requirement for all refractive lens design with two materials (K. Vogler et al, 157-nm Sym., Dana Point, May ‘00).

- Efforts on-going at laser vendors to develop line-narrowed lasers.

System Purging

• 1 ppm O_2 level purging feasibility demonstrated (S. Owa, Nikon, 157-nm Symposium, Dana Point, May ‘00).

• Hydrocarbon successfully filtered to <1ppB (M. DeMarco *et al*, SVGL, 157-nm Symposium, Dana Point, May ‘00).

• Same level of accomplishment reported by R. Miller *et al* of UltratechStepper at the 57-nm Symposium, Dana Point, May ‘00.

Tool Status

• Small field systems available for resist development.

• Miniscanners available Q4‘00.

• Full field systems available in Q1‘02

• Production systems available in Q4‘02 and ‘03

157-nm Challenge: Resist Material

Resist Issues

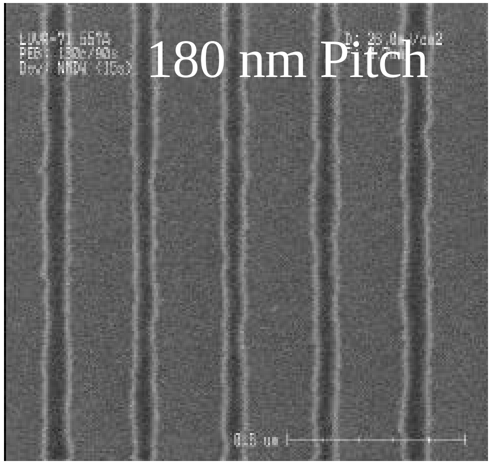
• Current resists too opaque (high absorption) at 157-nm.
• 248-nm/193-nm data do not predict 157-nm performance
• Completely new materials platforms (silicon and fluorine) required for single layer and will take long time to develop

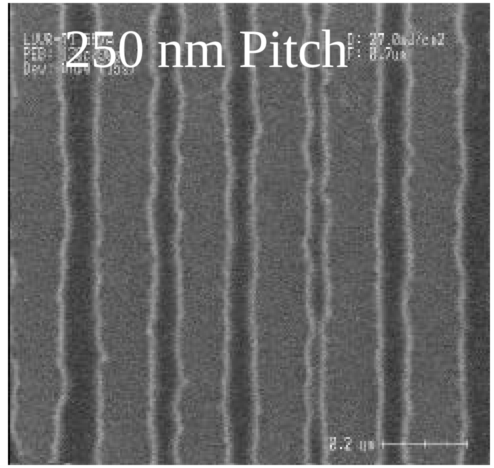
Strategy

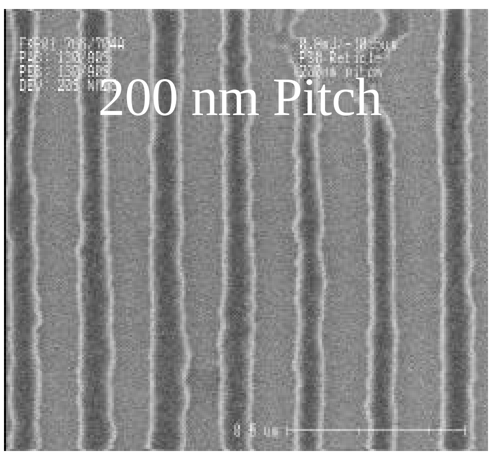
Ultra Thin Resist → Single Layer Resist

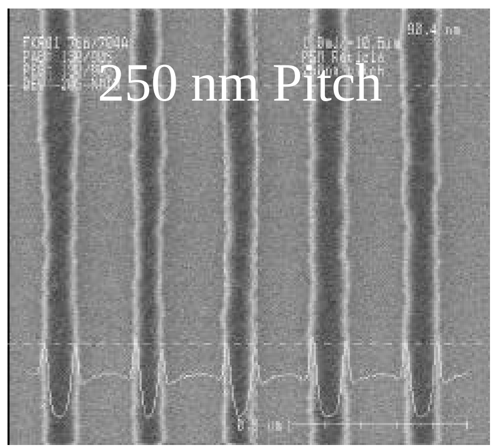
Big Issue - Resist Status

Ultra-Thin Resist Results



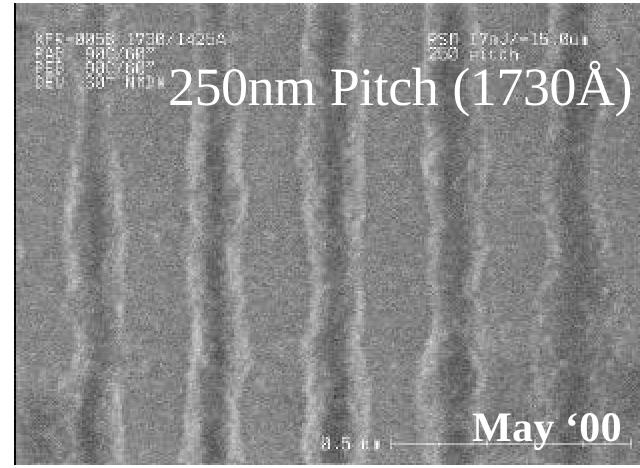


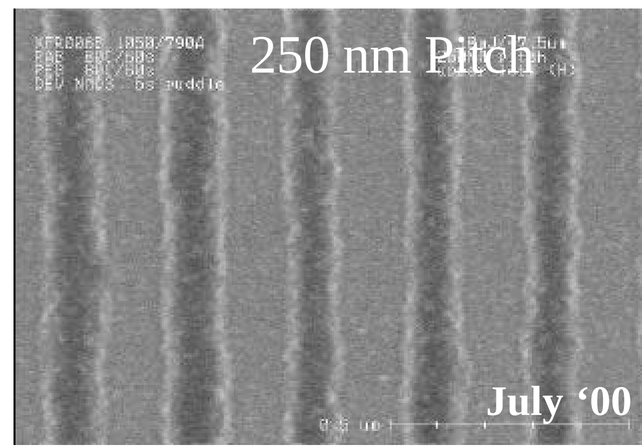




UTR Development Progressing At Various Resist Vendors

157-nm First SLR



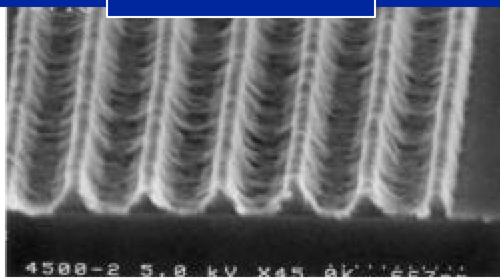


SRL Needs to Reach Maturity in 2 Years (3 Years for 193-nm)

Resist Issue: put in perspective

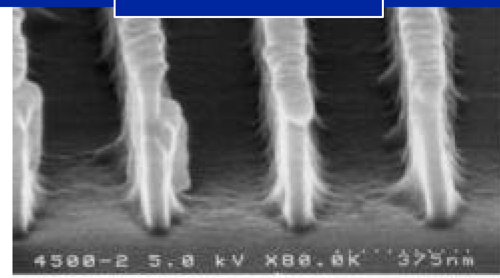
193nm Resists maturity: 2 - 3 years

1996



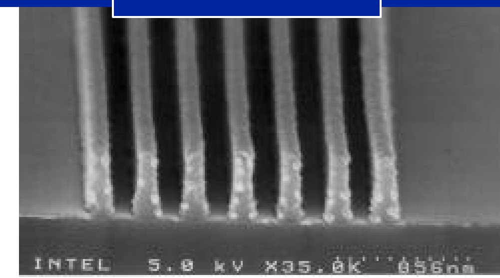
200-300 nm resolution
Dilute Develop
Poor etch resistance

1997



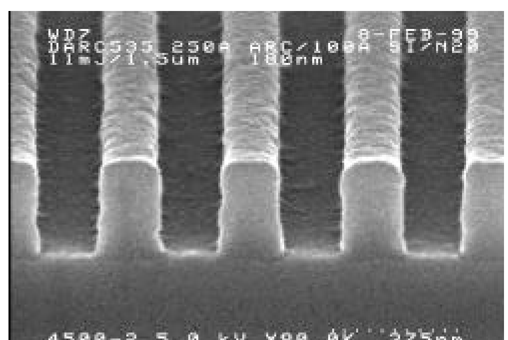
170-200 nm resolution
Dilute develop
Poor etch resistance/LER

1998



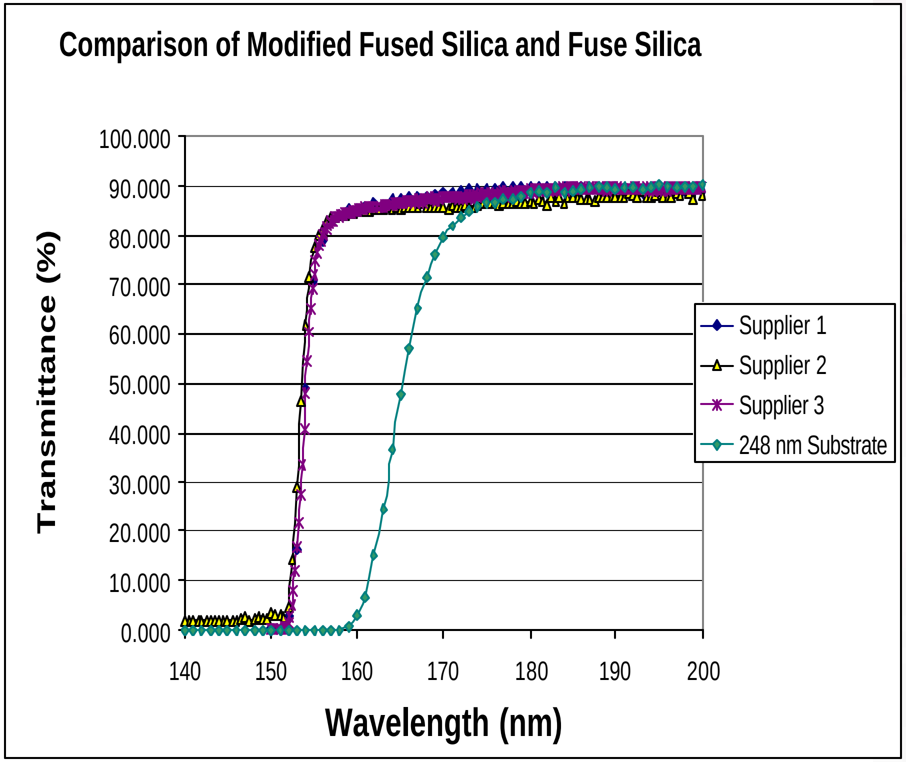
130-160 nm resolution
Standard develop
Etch resistance better/LER

1999

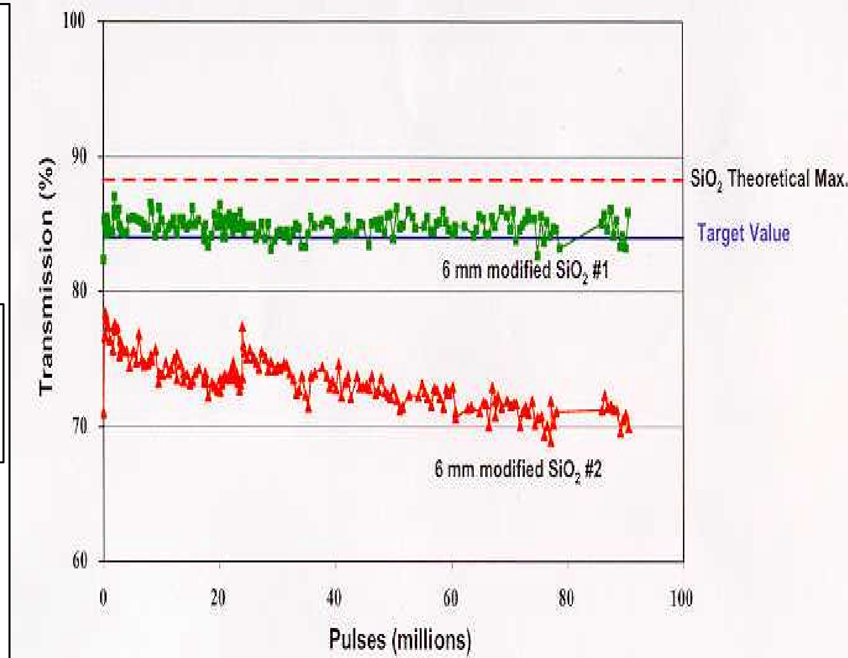


120-160 nm
Standard develop
Improved etch profiles, process window

157-nm Blank Substrate: Solution Proven



Transmission of newly developed mask blank substrate

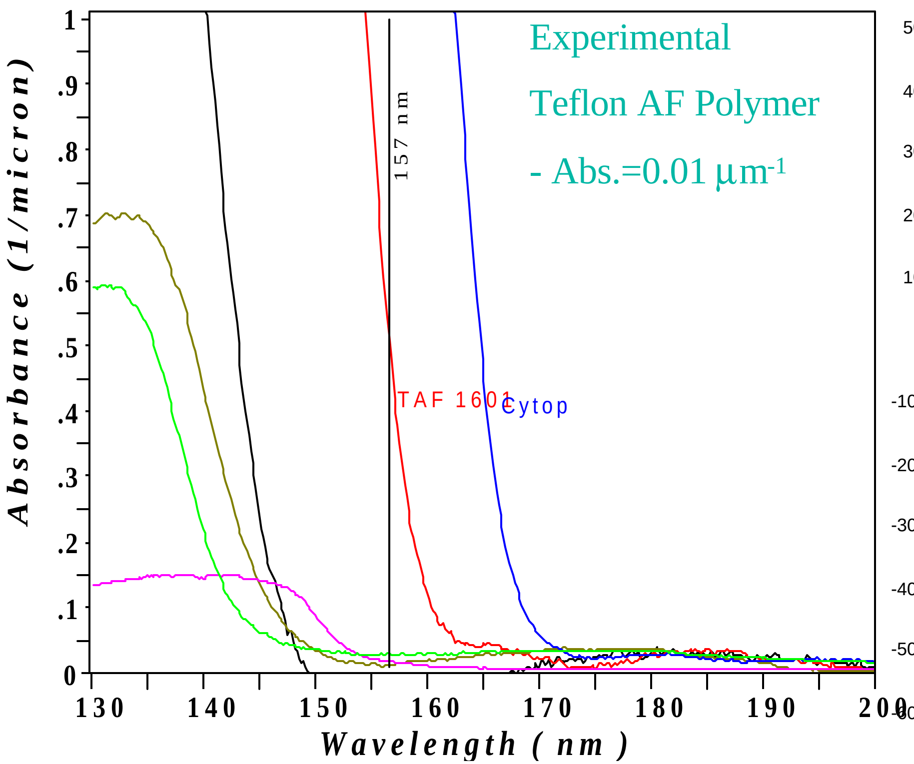


- Transmission measured *in-situ* with 157-nm laser
- Irradiation conditions: 157 nm, 0.15 mJ/cm^2/pulse, flowing N_2 ambient

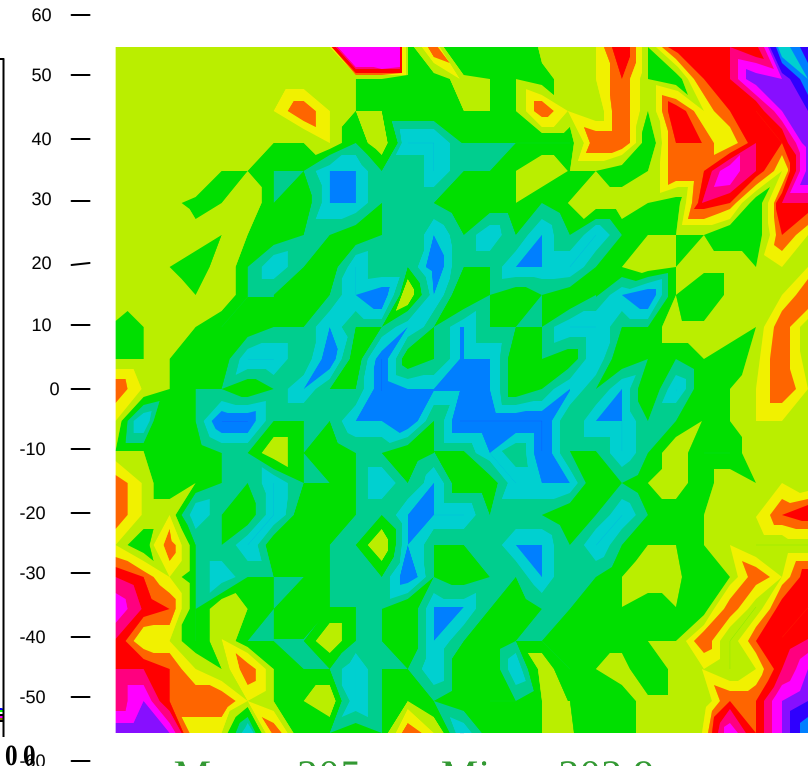
Radiation Durability

Mask blank material expected to meet requirements in '00

Pellicle: Still An Issue



Newly developed polymeric pellicle materials (J. Gordon of DPI, ISMT 157 nm Litho Symposium, May '00, Dana Point, Ca.)

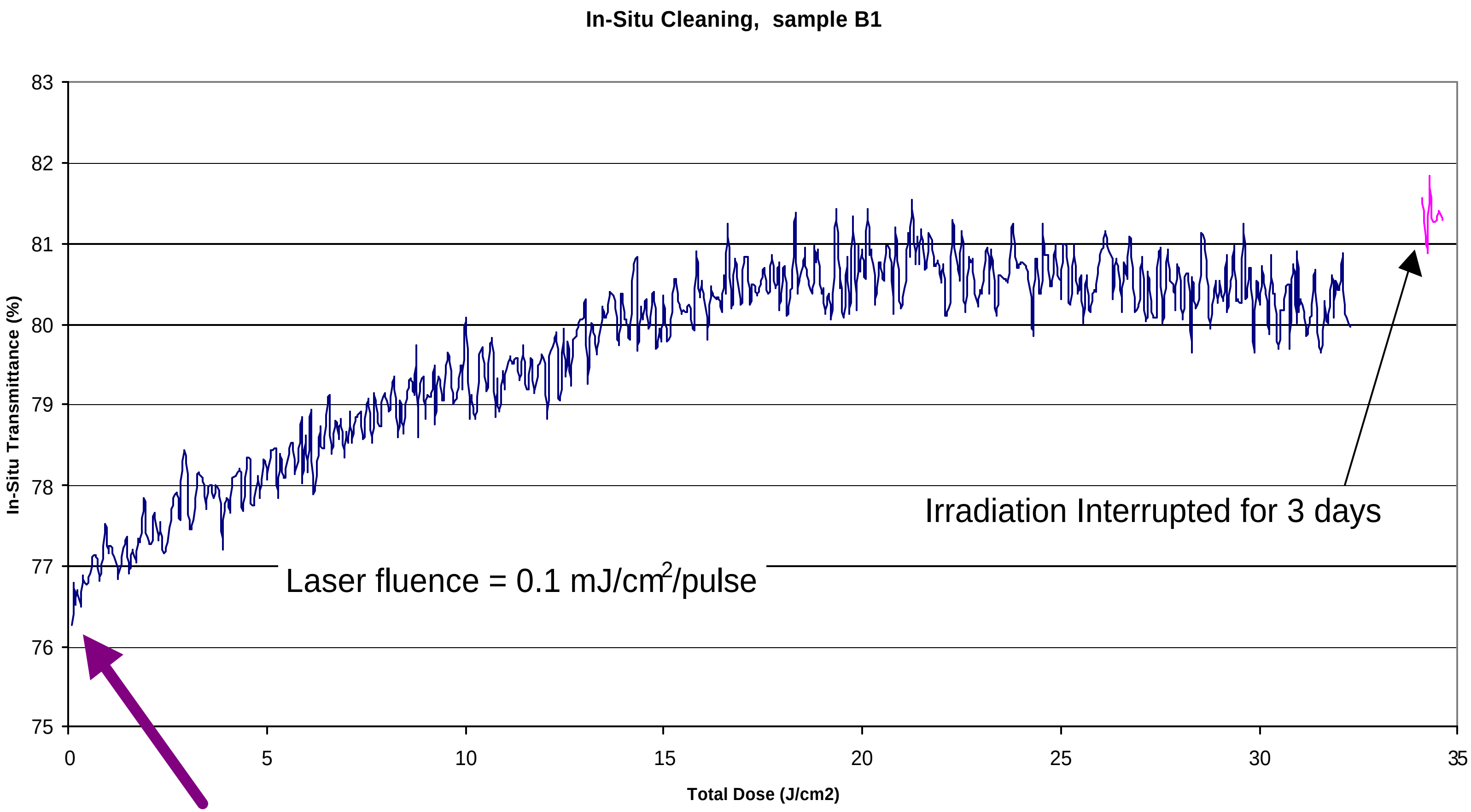


Max = 305µm, Min = 302.9 µm

3s = 0.75 mm

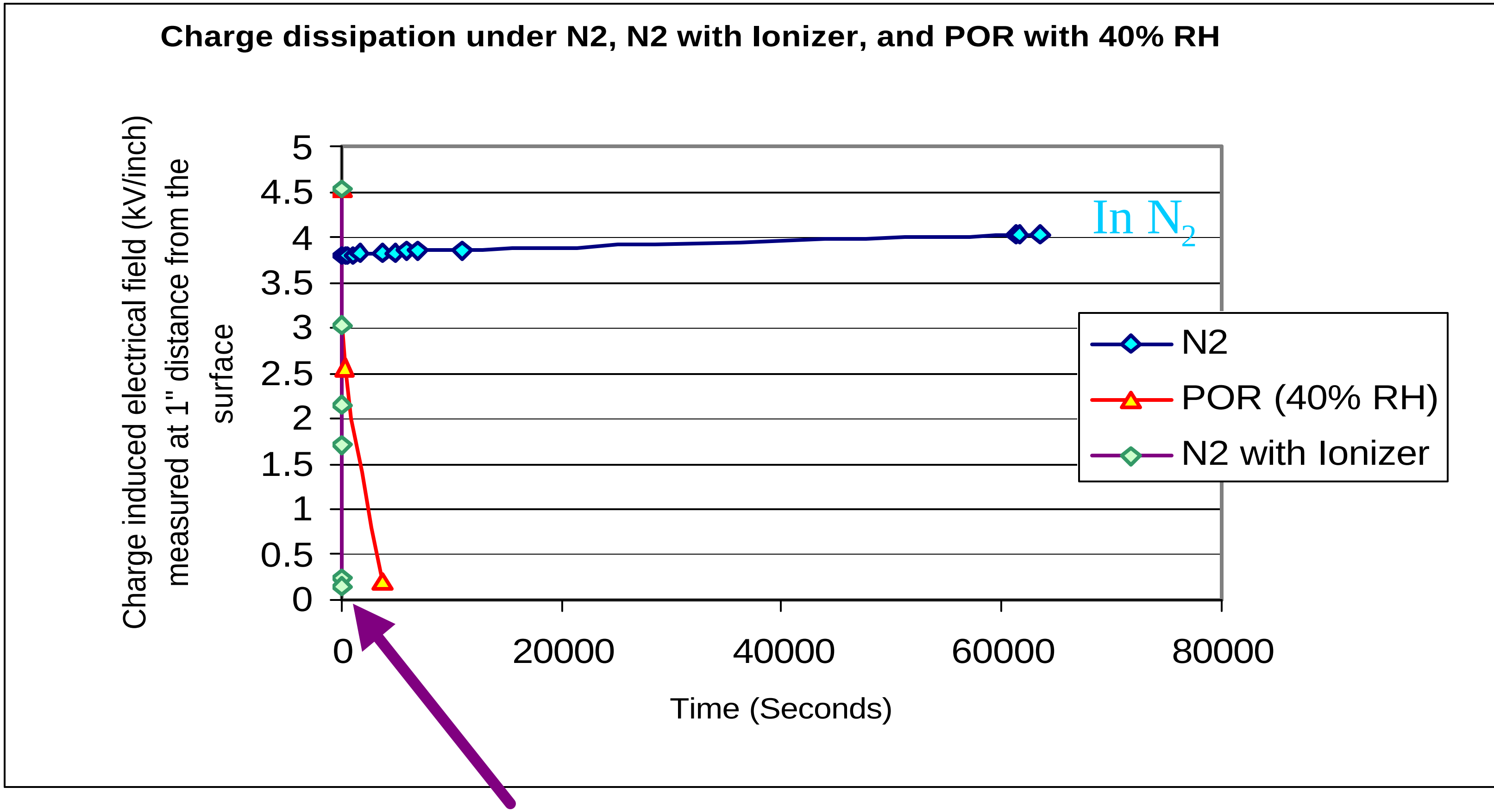
Example of thickness uniformity of hard pellicle (Courtesy of Kikugawa of Asahi Glass)

157 nm Reticle Handling: Surface Contamination



* Surface contamination an issue but solution seems to exist. *In-situ* clean expected.
* 172-nm excimer lamp and Hg Lamp (253.7 & 184.9 nm) reported.

157 nm Reticle Handling: ElectroStatic Discharge (ESD)

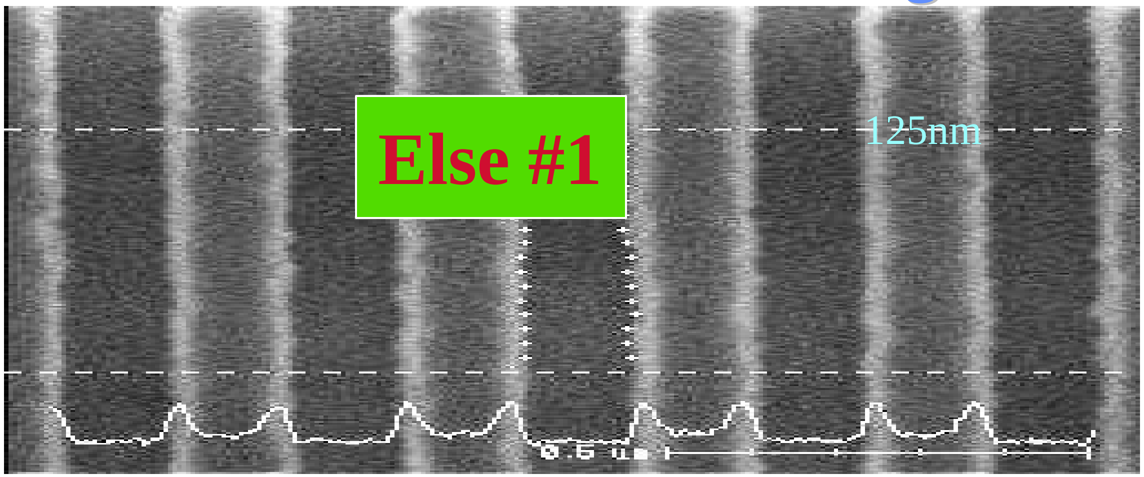


Charge dissipated in less than 50 seconds **in N_2 with ionizer**

ESD an issue in a dry environment but technical solution seems to exist (ionizers) for both global and local ESD prevention.

157nm Challenge: Be on Time or Else!

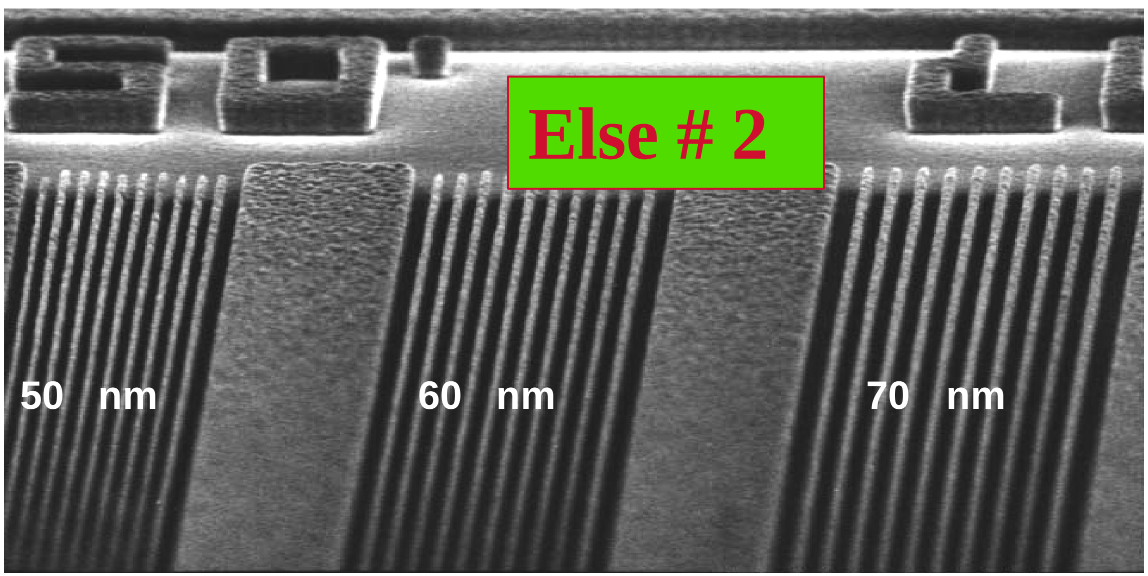
Alternative Technologies to 157-nm



280nm Pitch

193nm/0.60NA

Comm.Resist

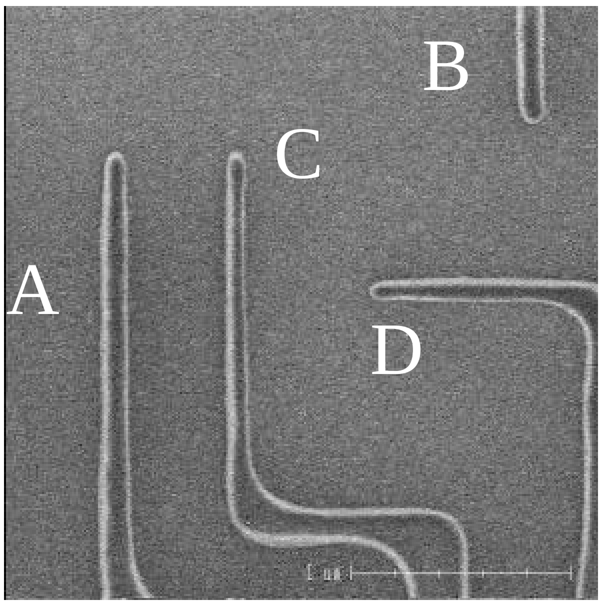


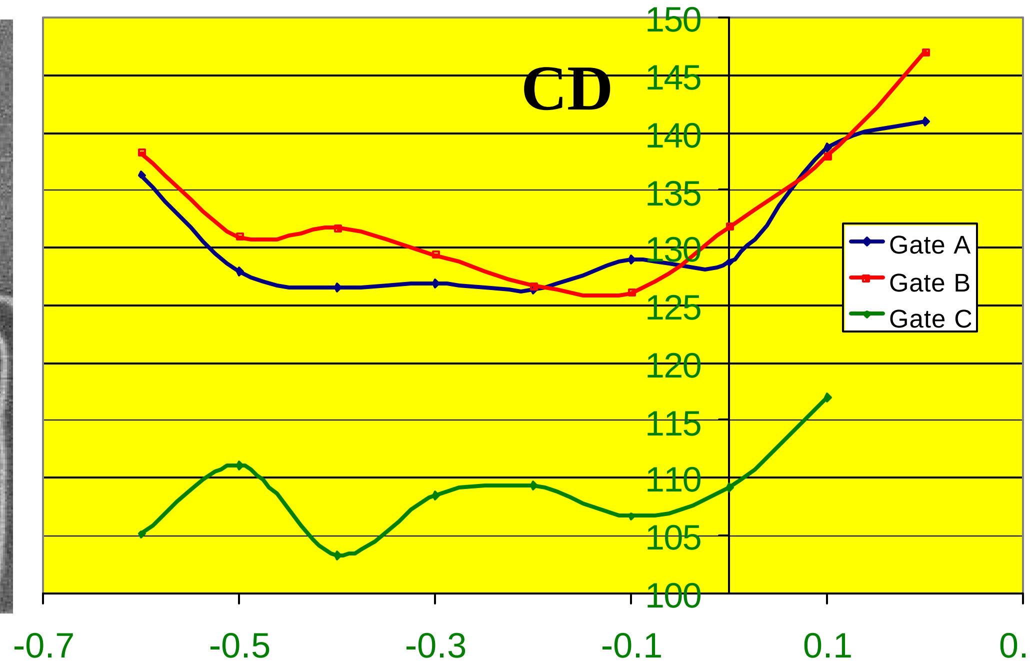
Etched Poly Si with **EUV**

Source: Sandia

Design Rules Restrictions

DF APSM, 248nm/0.68





C/D Phase Conflict

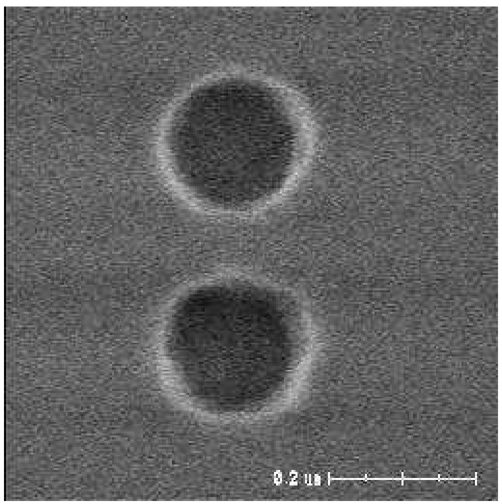
Focus

Design Rules Restrictions

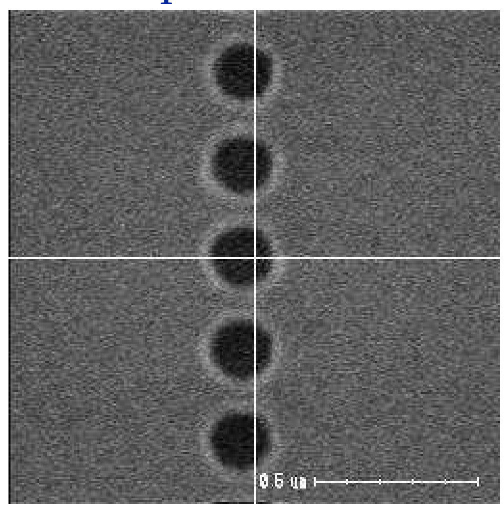
Both APSM and HTEPSM Require DRR

9% Ternary EPSM

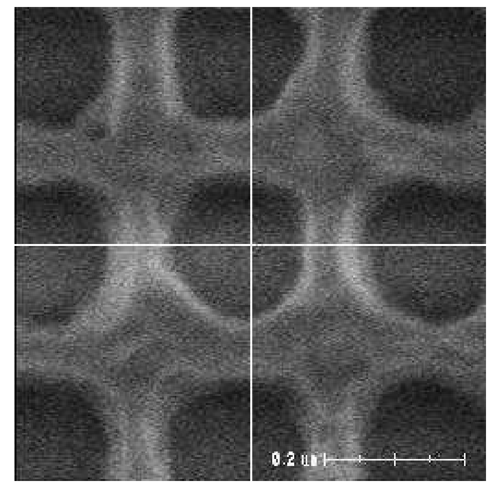
k_1=0.435



Pair



1D Array



2D Array

280nm Pitch, 193nm, NA=0.60

157nm Lithography Program: *Report Card*
(Courtesy of R. Harbison of ISMT)

	Jan-99	Mar-99	Jun-99	May-00	Issues/Comments
Mask					***Issue:* Transmission at 157nm**
-Reticle	⬢	▽	▽	▽	***Commercialization plan available. Product plates avail YE02***
-Pellicle	⬢	⬢	▽	⬢	***Research work underway. Limited supplier data > 90% transmission. Recent durability data looks promising***
-Writers	▽	▽	▽	▽	***130nm Tool - 3 month delay/prototype avail 2Q00 100nm Prototype avail 1Q02***
-Repair	▽	▽	▽	▽	***100nm Tool (Prototype) avail 3Q03***
-Inspection	▽	▽	▽	▽	***Actinic plan TBD/Resolution Capability actions in place***
-Processing	▽	▽	▽	▽	***Addressed via 157nm contamination mask group***
-PSM Material	▽	▽	▽	▽	***Plan target 1Q2000***
Exposure Tools					***Microstepper-1Q00; Miniscanner-9/00; FF Prototype - 4Q01***
-Materials					
Lens (CaF_2)	▽	▽	▽	▽	***Yield/Quality Enhancements underway***
Coatings	▽	▽	▽	▽	***ARC measurements up to 98% transmission - Lifetime remains focus item***
-Lasers	●	●	●	●	***Line narrow effort underway.***
-Overlay	▽	▽	▽	▽	***35nm @ 100 25nm @ 70***
-Purging/Ctmn			⬢	⬢	***Issue:* H_2O & O_2 severely attenuates 157nm radiation. Top priority for exposure tools suppliers**

Legend

⬢ **Requires Invention/Potential Showstopper**

▽ **Critical Issue/Development Required**

● **Solution Known**

157nm Lithography Program: *Report Card*

Resist					***Major Critical Issue***
-Chemistry	▽	▽	▽	⬣	***3 companies have data on platform feasibility.***
-Performance	⬣	⬣	⬣	⬣	***Current materials limited to 60nm***
Metrology -Infrastructure	▽	▽	▽	▽	***Issue:*** ***(1)100nm node is perceived limit of CD SEMS. Options to be explored: holography, scatterometry, etc. (2)At l metrology underway.***
CoO	⬣	▽	▽	▽	***Initial CoO indicates 193 & rets ~ 157 binary***
Timing ***ISMT Roadmap*** -100nm-03 mfg.	⬣	⬣	⬣	⬣	***It is highly probable that this piloting start date will move to 2002***

Legend

⬣ **Requires Invention/Potential Showstopper**

▽ **Critical Issue/Development Required**

● **Solution Known**

Summary

◆ The Intel strategy for pitch scaling is to drive wavelength reduction: 248nm → 193nm → 157nm → EUV.

◆ 157-nm has gained world-wide industrial support as post 193-nm.

◆ Not A One-Node Technology, i.e., 100-nm, 70-nm, and beyond.

◆ Imaging Simulation shows feasibility of 55-nm L/S and 25-nm Isolated Line using Alt-PSM (Owa, ISMT 157 nm Litho Symposium, May '00, Dana Point, Ca.)

◆ Significant progress has been made in many areas: lens materials and AR coating, laser, exposure system purging, micro-contamination and material out-gassing, mask materials and handling.

Summary

- **Key remaining challenges include:**
  - ⇨ **Schedule**
  - ⇨ **CaF_2 quality and supply**
  - ⇨ **SLR material**
  - ⇨ **Pellicle material**
- **Significant progress is expected in '00 and '01 as major 157-nm lithography programs start worldwide.**

Thank You